

PATENT COOPERATION TREATY

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

From the INTERNATIONAL BUREAU

To:

Assistant Commissioner for Patents
United States Patent and Trademark
Office
Box PCT
Washington, D.C.20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 05 September 2000 (05.09.00)	
International application No. PCT/US99/29864	Applicant's or agent's file reference 30794.58WOU1
International filing date (day/month/year) 15 December 1999 (15.12.99)	Priority date (day/month/year) 16 December 1998 (16.12.98)
Applicant SHERWIN, Mark, Stephen et al	

1. The designated Office is hereby notified of its election made:

☒ in the demand filed with the International Preliminary Examining Authority on:
05 July 2000 (05.07.00)

☐ in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was
☐ was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No.: (41-22) 740.14.35	Authorized officer <div style="text-align: right;">Olivia TEFY</div> Telephone No.: (41-22) 338.83.38
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PATENT COOPERATION TREATY

PCT

**NOTIFICATION OF THE RECORDING
OF A CHANGE**

(PCT Rule 92bis.1 and
Administrative Instructions, Section 422)

From the INTERNATIONAL BUREAU

To:

ORLER, Anthony, J.
Gates & Cooper LLP
6701 Center Drive West, Suite 1050
Los Angeles, CA 90045
ETATS-UNIS D'AMERIQUE

Date of mailing (day/month/year) 12 March 2001 (12.03.01)	
Applicant's or agent's file reference 30794.58WOU1	IMPORTANT NOTIFICATION
International application No. PCT/US99/29864	International filing date (day/month/year) 15 December 1999 (15.12.99)

1. The following indications appeared on record concerning: <input type="checkbox"/> the applicant <input type="checkbox"/> the inventor <input checked="" type="checkbox"/> the agent <input type="checkbox"/> the common representative									
Name and Address ORLER, Anthony, J. Gates & Cooper 6701 Center Drive West, Suite 1050 Los Angeles, CA 90045 United States of America	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px;">State of Nationality</td> <td style="padding: 2px;">State of Residence</td> </tr> <tr> <td colspan="2" style="padding: 2px;">Telephone No. 310 641 8797</td> </tr> <tr> <td colspan="2" style="padding: 2px;">Facsimile No. 310641 8798</td> </tr> <tr> <td colspan="2" style="padding: 2px;">Teleprinter No.</td> </tr> </table>	State of Nationality	State of Residence	Telephone No. 310 641 8797		Facsimile No. 310641 8798		Teleprinter No.	
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Facsimile No. 310641 8798									
Teleprinter No.									
2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning: <input type="checkbox"/> the person <input type="checkbox"/> the name <input checked="" type="checkbox"/> the address <input type="checkbox"/> the nationality <input type="checkbox"/> the residence									
Name and Address ORLER, Anthony, J. Gates & Cooper LLP 6701 Center Drive West, Suite 1050 Los Angeles, CA 90045 United States of America	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px;">State of Nationality</td> <td style="padding: 2px;">State of Residence</td> </tr> <tr> <td colspan="2" style="padding: 2px;">Telephone No. 310 641 8797</td> </tr> <tr> <td colspan="2" style="padding: 2px;">Facsimile No. 310641 8798</td> </tr> <tr> <td colspan="2" style="padding: 2px;">Teleprinter No.</td> </tr> </table>	State of Nationality	State of Residence	Telephone No. 310 641 8797		Facsimile No. 310641 8798		Teleprinter No.	
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Facsimile No. 310641 8798									
Teleprinter No.									
3. Further observations, if necessary: 									
4. A copy of this notification has been sent to: <table style="width: 100%;"> <tr> <td><input checked="" type="checkbox"/> the receiving Office</td> <td><input type="checkbox"/> the designated Offices concerned</td> </tr> <tr> <td><input type="checkbox"/> the International Searching Authority</td> <td><input checked="" type="checkbox"/> the elected Offices concerned</td> </tr> <tr> <td><input type="checkbox"/> the International Preliminary Examining Authority</td> <td><input type="checkbox"/> other:</td> </tr> </table>		<input checked="" type="checkbox"/> the receiving Office	<input type="checkbox"/> the designated Offices concerned	<input type="checkbox"/> the International Searching Authority	<input checked="" type="checkbox"/> the elected Offices concerned	<input type="checkbox"/> the International Preliminary Examining Authority	<input type="checkbox"/> other:		
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<input type="checkbox"/> the International Preliminary Examining Authority	<input type="checkbox"/> other:								

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No.: (41-22) 740.14.35	Authorized officer <p style="text-align: center;">Eugénia Santos</p> Telephone No.: (41-22) 338.83.38
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PATENT COOPERATION TREATY

PCT

**NOTIFICATION CONCERNING
SUBMISSION OR TRANSMITTAL
OF PRIORITY DOCUMENT**

(PCT Administrative Instructions, Section 411)

From the INTERNATIONAL BUREAU

To:

ORLER, Anthony, J.
Gates & Cooper
6701 Center Drive West, Suite 1050
Los Angeles, CA 90045
ETATS-UNIS D'AMERIQUE

Date of mailing (day/month/year) 12 March 2001 (12.03.01)	
Applicant's or agent's file reference 30794.58WOU1	IMPORTANT NOTIFICATION
International application No. PCT/US99/29864	International filing date (day/month/year) 15 December 1999 (15.12.99)
International publication date (day/month/year) 22 June 2000 (22.06.00)	Priority date (day/month/year) 16 December 1998 (16.12.98)
Applicant THE REGENTS OF THE UNIVERSITY OF CALIFORNIA et al	

1. The applicant is hereby notified of the date of receipt (except where the letters "NR" appear in the right-hand column) by the International Bureau of the priority document(s) relating to the earlier application(s) indicated below. Unless otherwise indicated by an asterisk appearing next to a date of receipt, or by the letters "NR", in the right-hand column, the priority document concerned was submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b).
2. This updates and replaces any previously issued notification concerning submission or transmittal of priority documents.
3. An asterisk(*) appearing next to a date of receipt, in the right-hand column, denotes a priority document submitted or transmitted to the International Bureau but not in compliance with Rule 17.1(a) or (b). In such a case, **the attention of the applicant is directed** to Rule 17.1(c) which provides that no designated Office may disregard the priority claim concerned before giving the applicant an opportunity, upon entry into the national phase, to furnish the priority document within a time limit which is reasonable under the circumstances.
4. The letters "NR" appearing in the right-hand column denote a priority document which was not received by the International Bureau or which the applicant did not request the receiving Office to prepare and transmit to the International Bureau, as provided by Rule 17.1(a) or (b), respectively. In such a case, **the attention of the applicant is directed** to Rule 17.1(c) which provides that no designated Office may disregard the priority claim concerned before giving the applicant an opportunity, upon entry into the national phase, to furnish the priority document within a time limit which is reasonable under the circumstances.

<u>Priority date</u>	<u>Priority application No.</u>	<u>Country or regional Office or PCT receiving Office</u>	<u>Date of receipt of priority document</u>
16 Dece 1998 (16.12.98)	60/112,439	US	03 Apr 2000 (03.04.00)
08 Marc 1999 (08.03.99)	60/123,220	US	03 Apr 2000 (03.04.00)

<p style="text-align: center;">The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland</p> <p>Facsimile No. (41-22) 740.14.35</p>	<p>Authorized officer</p> <p style="text-align: center; font-weight: bold;">Eugénia Santos</p> <p>Telephone No. (41-22) 338.83.38</p>
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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 30794.58WOU1	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/US99/29864	International filing date (day/month/year) 15/12/1999	Priority date (day/month/year) 16/12/1998
International Patent Classification (IPC) or national classification and IPC G06N1/00		
Applicant THE REGENTS OF THE UNIVERSITY OF CALIFORNIA et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.



2. This REPORT consists of a total of 9 sheets, including this cover sheet.

- ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of 5 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☒ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☒ Certain defects in the international application
- VIII ☒ Certain observations on the international application

Date of submission of the demand 05/07/2000	Date of completion of this report 23.01.2001
Name and mailing address of the international preliminary examining authority:  European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Borotschnig, H Telephone No. +49 89 2399 7459 

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/US99/29864

I. Basis of this report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).):*

Description, pages:

1,3-15	as originally filed			
2,2A	as received on	20/12/2000	with letter of	18/12/2000

Claims, No.:

1-17	as received on	20/12/2000	with letter of	18/12/2000
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Drawings, sheets:

1/6-6/6	as originally filed
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2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/US99/29864

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

II. Priority

1. ☐ This report has been established as if no priority had been claimed due to the failure to furnish within the prescribed time limit the requested:
- ☐ copy of the earlier application whose priority has been claimed.
 - ☐ translation of the earlier application whose priority has been claimed.
2. ☒ This report has been established as if no priority had been claimed due to the fact that the priority claim has been found invalid.

Thus for the purposes of this report, the international filing date indicated above is considered to be the relevant date.

3. Additional observations, if necessary:
see separate sheet

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	8-10,14,16-17
	No:	Claims	1-7,11-13,15
Inventive step (IS)	Yes:	Claims	16-17
	No:	Claims	1-15
Industrial applicability (IA)	Yes:	Claims	1-17
	No:	Claims	

2. Citations and explanations
see separate sheet

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT**

International application No. PCT/US99/29864

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item II: Priority

1. The claims for priority are based on the two US applications 60/112,439 filed 1998-12-16 and 60/123,220 filed 1999-03-08. Both documents disclose embodiment 1 of the present invention (pp. 4-10, where an electron's *electronic* states - tunable via the *Stark effect* - serve to encode a qubit). The priority claims are thus valid for all claims clearly directed to only this embodiment (i.e. present claims 16 and 17). However, neither of the two documents discloses the second embodiment (pp. 10-13, where *spin-states* of a conduction band electron serve to encode a qubit). Since the priority documents do not contain any indication regarding this second embodiment, according to Rule 33.1 PCT, document D4 forms part of the prior art for all claims which can be interpreted to cover also the second embodiment (i.e. present claims 1-15).

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

2. Reference is made to the following documents:
 - D1: BARENCO A ET AL: 'Conditional quantum dynamics and logic gates' PHYSICAL REVIEW LETTERS, 15 MAY 1995, USA, vol. 74, no. 20, pages 4083-4086, ISBN: 0031-9007
 - D3: SHERWIN M S ET AL: 'Quantum computation with quantum dots and terahertz cavity quantum electrodynamics' PHYSICAL REVIEW A (ATOMIC, MOLECULAR, AND OPTICAL PHYSICS), NOV. 1999, APS THROUGH AIP, USA, vol. 60, no. 5, pages 3508-3514, XP000891574 ISBN: 1050-2947
 - D4: IMAMOGLU A ET AL: 'Quantum information processing using quantum dot spins and cavity QED', Phys. Rev. Lett., Volume 83, Issue 20, pp. 4204-4207, 15 November 1999 (1999-11-15)
 - D5: IMAMOGLU A ET AL: 'Quantum information processing using quantum dot spins and cavity-QED', Los Alamos National Laboratory Preprint Archive <http://xxx.lanl.gov/abs/quant-ph/9904096> , (arXiv:quant-ph/9904096), 18 April 2000.

3. Present **claims 1-15** are formulated in such a broad manner that the subject matter of the claims also covers the second embodiment of the present invention. NB: The fact that the reference signs used in the present set of claims primarily refer to drawings related to the 1st embodiment is irrelevant as these reference signs are not limiting the scope of the claims and all claims covering both embodiments must be objected to (based upon the same reasoning that would apply to claims covering only the 2nd embodiment). Hence, the subject matter of claims 1-15 has essentially been pre-disclosed by the inventors in D4:
- 3.1 As to **claim 1**, D4 discloses a method for effecting gate operations using one or more semiconductor quantum bits (cf. D4 abstract), wherein the semiconductor quantum bits are contained in a cavity (ibid.), an electromagnetic field is applied to excite the semiconductor quantum bits to one or more energy levels (D4 pg. 4204 right col. line 34-pg. 4205, cf. also Figs. 1 and 2), and the semiconductor quantum bits so excited contain information used to implement the gate operations (cf. D4 abstract), comprising: coherently coupling the semiconductor quantum bits using a mode in the cavity that has a resonant frequency substantially coincident with a transition between the energy levels of the semiconductor quantum bits (cf. D4, abstract, pg. 4204 left col. lines 24-26, pg. 4205 left col. lines 1-3, right col. lines 15-19). Hence the subject matter of claim 1 lacks novelty over D4.
- 3.2 Dependent **claims 2-7,10-13,15** do not introduce any features which are not already known from D4. In addition, slight modifications or additions (as given in **claims 8-10,14**) are obvious over D4: Claim 2 (Fig. 1), Claim 3 (pg. 4204 right col. lines 32-34 "single conduction band electron"), Claim 4 (pg. 4204 right col. lines 36-38), Claim 5 (ibid. and Fig. 2), Claim 6 (pg. 4207 left col. lines 3-13), Claim 7 (ibid.), Claims 8-10 (obvious alternative implementations for Fig. 1), Claim 11 (Fig. 1), Claim 12 (pg. 4204 right col. lines 34-35), Claim 13 (pg. 4205 last paragraph), Claim 14 (obvious given Fig. 1), Claim 15 (Fig. 1). Hence the subject matter of claims 2-7,11-13,15 lacks novelty over D4 while the subject matter of claims 8-10,14 cannot be considered to be inventive over D4.

4. As to **claims 16 and 17**, document D1 discloses a method of storing information in quantum states of electrons in electron doped quantum dots, wherein voltages are applied to one or more gates to control the energy levels of the electrons in the quantum dots (cf. D1, Fig. 1) and to effect a controlled NOT operation. D1 also discloses how to alternatively transfer the state of a cavity field from and to an auxiliary Rydberg atom tuned to the resonant frequency of the cavity (cf. D1, pg. 4085) to effect a controlled NOT operation.
- 4.1 However, regarding **claim 16**, D1 fails to disclose manipulating the states of an electron in a quantum dot by tuning the energy levels of the electron into and out of resonance with the frequencies of a cavity and laser beams via voltages applied to one or more gates controlling the energy levels of the electrons in the quantum dots. As this feature cannot be derived from the available prior art the subject matter of claim 16 is novel and involves an inventive step.
- 4.2 Regarding **claim 17**, document D1 also does not disclose effecting a controlled NOT operation involving any pair of quantum dots by a sequence of voltage pulses across the gates which tune the energy levels of the quantum dots into resonance with frequencies of the cavity or a laser beam. Since also this feature cannot be derived from the applicable prior art the subject matter of claim 17 is also considered to be novel and to involve an inventive step.

Re Item VII

Certain defects in the international application

5. The application contains three independent claims of the same category, having overlapping scope. Therefore the set of claims as a whole is not concise and lacks clarity: an undue burden is placed on third parties seeking to determine the extent of protection, so that the requirements of Article 6 PCT are not met. In the present case only one independent method claim (e.g. similar to present claim 16) would suffice to clearly define the invention (i.e. embodiment 1), with dependent claims as appropriate (e.g. to define the controlled NOT operation presently covered by independent claim 17).

6. Regarding claims 16 and 17, it can be implicitly understood from the claims that the control voltages will affect the electronic energy levels of the electrons in the quantum dots via the Stark effect. The intelligibility of the present set of claims is reduced since this issue is not clarified explicitly, Art. 6 PCT.
7. The bracketing of the employed expression (CNOT) in claim 17 induces uncertainties regarding the scope of the bracketed expression (as bracketing is also used to refer to the figures without limiting the claim's scope), Art. 6 PCT.

Re Item VIII

Certain observations on the international application

8. The inventors have presented the claimed invention to the scientific community in articles published in Physical Review A (cf. D3, first embodiment: present claims 16 and 17) and Physical Review Letters (cf. D4 and D5, second embodiment). In these publications the inventors indicate that the proposed solution cannot presently be built by a skilled person using only currently available technology: The most relevant statements in this respect can be found in D3, page 3511, right hand column, second last paragraph; page 3512 left column, lines 20-21, right hand column, second last paragraph and page 3513 section "Conclusions" in which the authors admit that "new types of quantum dots must be constructed, gated and loaded with single electrons; few mode THz cavities with extremely high Q must be fabricated; and single THz photons must be detected. Although **each of these worthy challenges is beyond today's state of the art**, the rapid pace of progress in materials science and THz technology makes us optimistic that these obstacles will be overcome in the not too distant future" (emphasis added. The fact that such statements were already made in the US priority document application number 60/123,220 of the present international application and later on repeated in D3 only increases their importance). With respect to D4, the most relevant statements are found in end-note [15] where it is said that "strong coupling of a quantum dot to a single cavity mode, **which is a principal feature of the proposed scheme, is still not observed experimentally**" (emphasis added. Again it is noteworthy that the same statement is also repeated on April 18, 2000, i.e. *after* the filing date of the present international application, as end-note [16] in the corresponding document D5).

- 8.1 According to Article 5 PCT the patent application has to disclose the invention in a manner sufficiently clear and complete for it to be carried out by a person skilled in the art. The purpose of this provision is "to ensure that the international application contains **all the technical information** required to enable a skilled person **to put the invention into practice**" (emphasis added), cf. PCT Guidelines II-4.1(i). The PCT Guidelines IV-8.6 define the person skilled in the art "to be an ordinary practitioner aware of what was **common general knowledge in the art at the relevant date.**" (emphasis added)
- 8.2 The issue is not whether the claimed invention can be built in principle but rather whether the skilled person was able - at the filing date of the application - to put the invention into practice by using only commonly available technology in a standard manner, i.e. without the need for further experimental break-throughs.

The cited publications (and also their use in this report) only appear to demonstrate that the invention can be conceived and that most of its important physical properties can be derived and discussed without being able to actually build the device. Especially in physics this is not an uncommon situation. The same comments would also apply to such "exotic" (but still conceivable) devices as a power plant extracting energy from rotating black holes (suggested by Penrose) or to other imaginable devices based on "Gedanken-experiments".

Hence, in the present case, the question remains whether an ordinary practitioner would actually have been able to put the invention into practice at the date of filing using only common general knowledge and the disclosure of the application. In conclusion, the strong statements made by the inventors themselves raise severe doubts as to whether the present application as a whole does at all fulfill the primary requirements of Article 5 PCT.

indefinitely, which provides the interest in quantum computation and machines that can perform quantum computation.

However, the implementation of a large-scale quantum computer has remained a technological challenge. The qubits must be well isolated from the influence of the environment, but must remain manipulatable in individual units to initialize the computer, perform quantum logic operations, and measure the result of the computation.

Implementations of such a quantum computer have been proposed using atomic beams, trapped atoms and/or ions, bulk nuclear magnetic resonance, nanostructured semiconductors, and Josephson junctions. However, each scheme proposed has limitations that make large-scale implementation difficult and very limiting in performance.

For example, proposals using trapped atoms or ions, qubits couple with collective excitations or cavity photons. This coupling enables two-bit gates involving an arbitrary pair of qubits which makes programming straightforward. However, these schemes require serial gating schemes, whereas error correction schemes require parallelism, thereby limiting the usefulness of data gathered using an atomic or ion trapping machine.

In the semiconductor and superconductor schemes, only nearest-neighbor qubits can be coupled, and significant overhead is required to couple distant qubits. However, these machines can perform some gate operations in parallel, which allows for some error correction.

It can be seen, then, that there is a need in the art for a quantum computer. It can also be seen, then, that there is a need in the art for a quantum computer that can perform parallel gate operations. It can also be seen, then, that there is a need in the art for a quantum computer that can perform parallel gate operations without significant qubit overhead.

SUMMARY OF THE INVENTION

To overcome the limitations in the prior art described above, and to overcome other limitations that will become apparent upon reading and understanding the present specification, the present invention discloses an apparatus and method for quantum computing. The apparatus comprises a control bit structure, a target bit structure, and gate electrodes, coupled to the control bit structure and the target bit structure, for applying a voltage across the control bit structure and the target bit structure, wherein the control bit structure and the target bit structure obtain quantum levels of excitation from

WHAT IS CLAIMED IS:

1. A quantum computer, comprising:
a control bit structure;
a target bit structure; and
5 gate electrodes, coupled to the control bit structure and the target bit structure, for applying a voltage across the control bit structure and the target bit structure, wherein the control bit structure and the target bit structure obtain quantum levels of excitation from the applied voltages based on an initial excitation level of the control bit structure and an initial excitation level of the target bit structure.
- 10 2. The quantum computer of claim 1, wherein the control bit structure is a quantum dot.
3. The quantum computer of claim 2, wherein the target bit structure is a
15 quantum dot.
4. The quantum computer of claim 1, wherein the control bit structure and the target bit structure each comprise:
an edge layer of a first semiconductor material;
20 a first disk of a second semiconductor material, coupled to the edge layer;
a first barrier layer, coupled to the first disk;
a second disk of the second semiconductor material, coupled to the first barrier layer;
a second barrier layer, coupled to the second disk;
25 a third disk of the second semiconductor material coupled to the second barrier layer; and
a second edge layer of the first material, wherein a bandgap of the first material is larger than a bandgap of the second material.
- 30 5. The quantum computer of claim 4, wherein the second disk is thicker than the first disk and the third disk.
6. The quantum computer of claim 4, wherein the first material is gallium
arsenide.

REPLACED BY
ART 34/2001

7. The quantum computer of claim 6, wherein the second material is aluminum gallium arsenide.

8. The quantum computer of claim 1, wherein the voltage is applied in a
5 sequence.

9. The quantum computer of claim 8, wherein the sequence comprises
a first pulse applied to the control bit structure;
a second pulse, applied to the target bit structure; and
10 a third pulse, applied to the control bit structure, the third pulse substantially the
same as the first pulse, wherein the sequence comprises a conditional NOT (CNOT)
function.

10. A method for quantum computing, comprising:
15 applying a first voltage across a control bit structure;
applying a second voltage across a target bit structure; and
obtaining quantum levels of excitation within the control bit structure and the
target bit structure based on the applied first and second voltages, an initial excitation
level of the control bit structure and an initial excitation level of the target bit structure.

20 11. The method of claim 10 wherein the control bit structure is a quantum
dot.

25 12. The method of claim 11, wherein the target bit structure is a quantum
dot.

13. The method of claim 10, wherein the control bit structure and the target
bit structure each comprise:
an edge layer of a first semiconductor material;
30 a first disk of a second semiconductor material, coupled to the edge layer;
a first barrier layer, coupled to the first disk;
a second disk of the second semiconductor material, coupled to the first barrier
layer;
a second barrier layer, coupled to the second disk;

REPLACED BY
ART 34 ADOT

a third disk of the second semiconductor material coupled to the second barrier layer; and

a second edge layer of the first material, wherein a bandgap of the first material is larger than a bandgap of the second material.

5

14. The method of claim 13, wherein the second disk is thicker than the first disk and the third disk.

15. The method of claim 13, wherein the first material is gallium arsenide.

10

16. The method of claim 15, wherein the second material is aluminum gallium arsenide.

17. The method of claim 10, wherein the first voltage and the second voltage are applied in a sequence.

15

18. The method of claim 17, wherein the sequence comprises a first pulse applied to the control bit structure;

a second pulse, applied to the target bit structure; and

20 a third pulse, applied to the control bit structure, the third pulse substantially the same as the first pulse, wherein the sequence comprises a conditional NOT (CNOT) function.

20

19. A method for making a quantum computer, comprising:

25

growing a first quantum dot layer on an edge layer;

growing a first barrier layer on the first quantum dot layer;

growing a second quantum dot layer on the first barrier layer;

growing a second barrier layer on the second quantum dot layer;

growing a third quantum dot layer on the second barrier layer; and

30

growing a second edge layer on the third quantum dot layer, wherein the edge layer, first quantum dot layer, first barrier layer, second quantum dot layer, second barrier layer, third quantum dot layer, and second edge layer comprise at least one bit in the quantum computer.

REPLACED BY
ART 34 AADT

20. A method to effect quantum gate operations between a first quantum dot and a second quantum dot in an array, comprising:

doping the first quantum dot with at least a first electron and the second quantum dot with at least a second electron; and

5 applying a field to at least the first quantum dot to selectively excite the first electron, wherein a state of the excited first electron contains information used to implement a digital gate.

10 21. The method of claim 20, wherein the array of quantum dots is contained in a cavity for electromagnetic radiation, and wherein a mode in the cavity has a resonant frequency substantially coincident with an intraband transition in the first quantum dot and the second quantum dot to couple the first quantum dot to the second quantum dot.

15 22. The method of claim 21, wherein the cavity for electromagnetic radiation is a whispering-gallery-mode resonator.

23. The method of claim 21, wherein the cavity for electromagnetic radiation is a defect in a photonic band-gap structure.

20 24. The method of claim 21, wherein the cavity for electromagnetic radiation is a superconductor.

25 25. The method of claim 20, wherein the information in the state of the first electron is contained in a spin-state of the first electron.

26. The method of claim 20, wherein the applied field is generated by one or more laser beam fields, each laser beam field having independently controllable frequencies, polarizations, and intensities.

30 27. The method of claim 26, wherein a first laser beam field incident on the first quantum dot shifts the energy levels of the first quantum dot via an ac-Stark effect.

28. The method of claim 26, wherein the applied field is a coherent electromagnetic field provided by a first laser beam and a second laser beam focused on

the first quantum dot, a first frequency of the first laser beam and a second frequency of the second laser beam differing by a coherent electromagnetic coupling frequency.

29. The method of claim 20, wherein the applied field is an externally applied magnetic field.

30. The method of claim 20, wherein the quantum gate operations result in a CNOT operation.

31. The method of claim 25, further comprising the step of reading the spin state information of the first electron and the second electron.

32. The method of claim 31, wherein the spin state information is determined by selective fluorescent emissions from a spin state of the first quantum dot.

33. The method of claim 20, wherein the first quantum dot and the second quantum dot are coupled in a substantially vertical manner.

34. The method of claim 20, wherein the first quantum dot and the second quantum dot are coupled in a substantially horizontal manner.

35. The method of claim 20, wherein the first quantum dot comprises an internal structure so the first quantum dot comprises a quantum bit in a quantum computer.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 30794.58W0U1	FOR FURTHER ACTION		see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
International application No. PCT/US 99/ 29864	International filing date (day/month/year) 15/12/1999	(Earliest) Priority Date (day/month/year) 16/12/1998	
Applicant THE REGENTS OF THE UNIVERSITY OF CALIFORNIA et al.			

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

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☐ furnished subsequently to this Authority in written form.

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☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

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2. ☐ **Certain claims were found unsearchable** (See Box I).

3. ☐ **Unity of Invention is lacking** (see Box II).

4. With regard to the **title**,

☒ the text is approved as submitted by the applicant.

☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

☒ the text is approved as submitted by the applicant.

☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No.

☒ as suggested by the applicant.

☐ because the applicant failed to suggest a figure.

☐ because this figure better characterizes the invention.

1
☐ None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/29864

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G06N1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G06N G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BARENCO A ET AL: "Conditional quantum dynamics and logic gates" PHYSICAL REVIEW LETTERS, 15 MAY 1995, USA, vol. 74, no. 20, pages 4083-4086, XP000910960 ISSN: 0031-9007	1-3, 10-12, 20, 30
Y	page 4083, left-hand column, line 1 -page 4086, left-hand column, line 36; figures 1, 2 ----- -/--	4-9, 13-19, 21, 26-28

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

26 May 2000

Date of mailing of the international search report

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International Application No

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KOUWENHOVEN L P ET AL: "Excitation spectra of circular, few-electron quantum dots" SCIENCE, 5 DEC. 1997, AMERICAN ASSOC. ADV. SCI, USA, vol. 278, no. 5344, pages 1788-1792, XP002138815 ISSN: 0036-8075 page 1788, left-hand column, line 1 -right-hand column, line 35; figure 1 ---	4-7, 13-16, 19
Y	MONROE C ET AL: "DEMONSTRATION OF A FUNDAMENTAL QUANTUM LOGIC GATE" PHYSICAL REVIEW LETTERS, US, NEW YORK, NY, vol. 75, no. 25, 18 December 1995 (1995-12-18), pages 4714-4717, XP000560055 ISSN: 0031-9007 page 4714, left-hand column, line 1 -page 4715, right-hand column, line 6 ---	8, 9, 17, 18, 21
Y	US 5 671 437 A (TAIRA KENICHI) 23 September 1997 (1997-09-23) column 5, line 47 -column 6, line 26; figure 6 ---	26-28
P, X	SHERWIN M S ET AL: "Quantum computation with quantum dots and terahertz cavity quantum electrodynamics" PHYSICAL REVIEW A (ATOMIC, MOLECULAR, AND OPTICAL PHYSICS), NOV. 1999, APS THROUGH AIP, USA, vol. 60, no. 5, pages 3508-3514, XP000891574 ISSN: 1050-2947 the whole document -----	1-18

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/29864

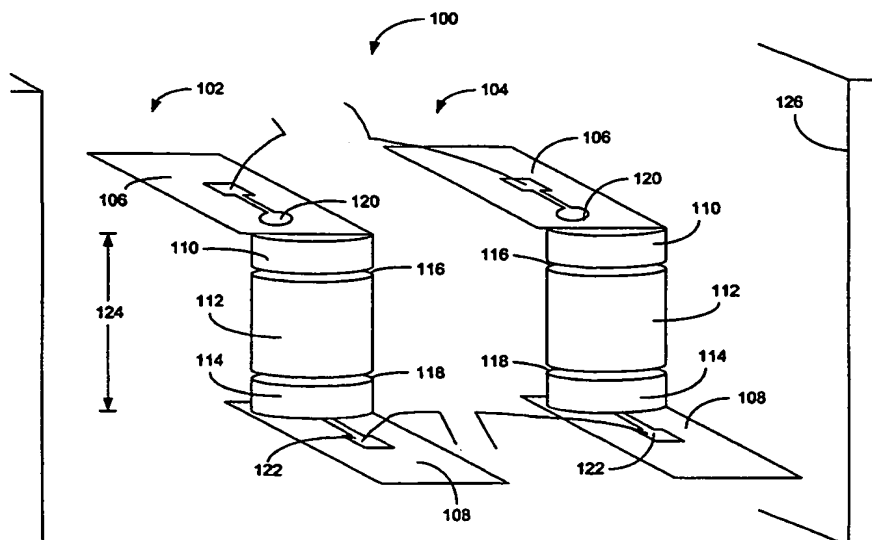
Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5671437 A	23-09-1997	JP 5081449 A	02-04-1993
		US 5613140 A	18-03-1997



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<p>(21) International Application Number: PCT/US99/29864</p> <p>(22) International Filing Date: 15 December 1999 (15.12.99)</p> <p>(30) Priority Data: 60/112,439 16 December 1998 (16.12.98) US 60/123,220 8 March 1999 (08.03.99) US</p> <p>(71) Applicant (for all designated States except US): THE REGENTS OF THE UNIVERSITY OF CALIFORNIA [US/US]; 1111 Franklin Street, 12th Floor, Oakland, CA 94607 (US).</p> <p>(72) Inventors; and (75) Inventors/Applicants (for US only): SHERWIN, Mark, Stephen [US/US]; 931 W. Campus Lane, Goleta, CA 93117 (US). IMAMOGLU, Atac [US/US]; 923 W. Campus Lane, Goleta, CA 93117 (US).</p> <p>(74) Agent: ORLER, Anthony, J.; Gates & Cooper, 6701 Center Drive West, Suite 1050, Los Angeles, CA 90045 (US).</p>		<p>(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p>Published With international search report.</p> <p>(88) Date of publication of the international search report: 31 August 2000 (31.08.00)</p>

(54) Title: QUANTUM COMPUTATION WITH QUANTUM DOTS AND TERAHERTZ CAVITY QUANTUM ELECTRODYNAMICS



(57) Abstract

A quantum computer is proposed in which information is stored in the two lowest electronic states of doped quantum dots. Multiple quantum dots are located in a microcavity, and a pair of gates control the energy levels in each quantum dot. A controlled NOT (CNOT) operations involving any pair of quantum dots can be effected by a sequence of gate voltage pulses which tune the quantum dot energy levels into resonance with frequencies of the cavity or a laser. The duration of a CNOT operation is estimated to be much shorter than the time for an electron to decohere by emitting an acoustic phonon.

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